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COMMENTS ON POPAE*

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I. Introduction

POPAE is proposed as a storage ring facility on a scale suitable to permit the collision of 1000 GeV protons with 1000 GeV protons and with 20 GeV electrons. Luminosity design goals are $10^{34}\text{cm}^{-2}\text{sec}^{-1}$ for p-p and $10^{32}\text{cm}^{-2}\text{sec}^{-1}$ for e-p. The figure of 1000 GeV for the protons arises more from the general atmosphere of optimism concerning superconducting magnets than from any physics hypothesis; the existence of high quality, economical and reliable dipole magnets would make feasible 1000 GeV proton storage rings of an overall size comparable to the Fermilab main accelerator. Given this overall size and desired e-p luminosity, the electron peak energy - 20 GeV - implies an rf system in the 10 megawatt range.

A few hours spent drawing a variety of arcs and straight lines on a Laboratory site map will convince one that there are a number of ways such a facility can be sketched, particularly if one takes the liberty of passing tunnels under existing construction and attributes higher and higher fields to superconducting magnets. In order to get on with the evolution of a design, it is useful to impose some constraints (if only temporarily) and consider a relatively specific geometry. The purpose of these remarks is to suggest a location and geometry, and to identify some questions for study.

*Remarks made at the opening session of a POPAE Workshop on September 9, 1974.

II. Scale, Location and Geometry

Let us set the scale by taking the radius of curvature of the protons to be consistent with that provided by 18 kilogauss magnets for 400 GeV protons, i.e., just under 750 meters. The peak energy possible then follows the developing capabilities of superconducting magnets. Setting the scale in this way sets a "floor" under the project; 400 GeV proton storage rings using magnets of more-or-less conventional design are interesting in themselves and could represent an intermediate step to the 1000 GeV region.

The various 1000 GeV rings described at the 1973 Aspen Summer Study assumed superconducting dipoles at 45 kilogauss, which is in agreement with the above assumption.[1] A typical layout - the one felt to be most reasonable at the study - is shown in Figure 1. Eight symmetrically located experimental insertions each 240 meters in length result in a geometry which can be located on the site in such a way as to have only modest interference with existing facilities and reasonable injection lines, especially if the Q-stub from the beam line to the Proton Area is to be developed anyway. However, the rings do pass through the region of most probable experimental area expansion and also through a substantial swamp.

At Aspen, 240 meters was taken as an adequate length to accommodate both the experiments and the machine optics necessary to the interaction regions. Studies[2] conducted since that time have suggested that 240 meters is insufficient; for example, a version of a high luminosity insertion requires 450 meters. High beta insertions appear to be even longer. High symmetry rings drawn with these longer insertions overlap the present experimental areas in plan view. One may think of building under the existing construction; however, the limestone bedrock encountered 55 to 78 feet underground[3] is an important aquifer penetration of which would appear to be undesirable.

A modified layout which avoids the problems mentioned above (while creating some of its own, of course) is sketched in Figure 2. The "racetrack" configuration permits two very long straight sections each containing a number of interaction regions. The absence of long straight sections in the semicircles at either end shrinks the east-west extent of the facility enough so that it fits comfortably on the site between the main accelerator and the power line running along the east site boundary. The rings cross the swamp at a point where it is narrow. Interference with existing experimental area expansion can be avoided. The close spacing of interaction regions permits economies in access, power distribution, and other conventional facilities aspects of the system. Finally, there is a valuable conceptual simplicity in this layout, for the straight section length required may be studied and adjusted with a minimum of coupling with the design of the semicircles at either end.

Two questions posed by this geometry come immediately to mind. First, if several interaction points are set up along a line, how severe is the background problem at one of them due to its neighbors? An estimate of the muon flux arising from a high luminosity intersection indicates that such background rates are significant but not intolerable.[4] Further study is needed. Second, what are the consequences of the apparent lowering of the symmetry of the system? In general, the less the symmetry, the greater the sensitivity to structure imperfections. However, a storage ring with a variety of types of interaction regions is inherently a low symmetry device and it is not obvious that in practical terms the racetrack configuration is considerably worse in this respect. This is not to say that the available symmetry should be ignored - if, for instance, there are to be two high luminosity points, then it would be prudent to place them (provisionally) at half-ring spacing. It would be interesting to make a comparison of the relative sensitivity to systematic dipole imperfections of two rings having, say, eight interaction regions of various sorts (high, low, and intermediate luminosity) with the regions located with maximum symmetry in the one and with two-fold periodicity in the other.

III. Proton-Proton and Electron-Proton Topology

Figures 1 and 2 are drawn at low resolution; they do not show where proton-proton or electron-proton collisions are to occur, or how many rings of magnets there are.

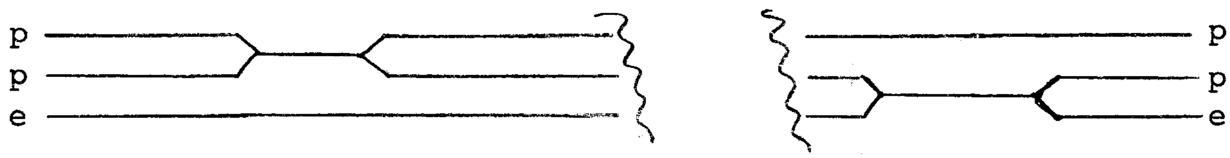
The most lavish p-p and e-p system discussed at Aspen involved four rings - two for proton-proton collisions concentric with two more for electron-proton, separated radially by a sufficient distance so that the pairs may be operated independently. Clearly, the less costly alternatives should be examined first.

At the other extreme is the two-ring version, where one of the rings is endowed with the capability of storing either 1000 GeV protons or 20 GeV electrons, and the two kinds of physics are done alternately. This case raises questions that, though easily identified, are not readily answerable. Can magnets be designed with fields suitable for beam storage at both 45 kilogauss and 900 gauss? Can an optics suitable for both electrons and protons be devised? How is the power delivered to the walls by synchrotron radiation from electrons to be handled in the confined environment of the high field superconducting magnet?

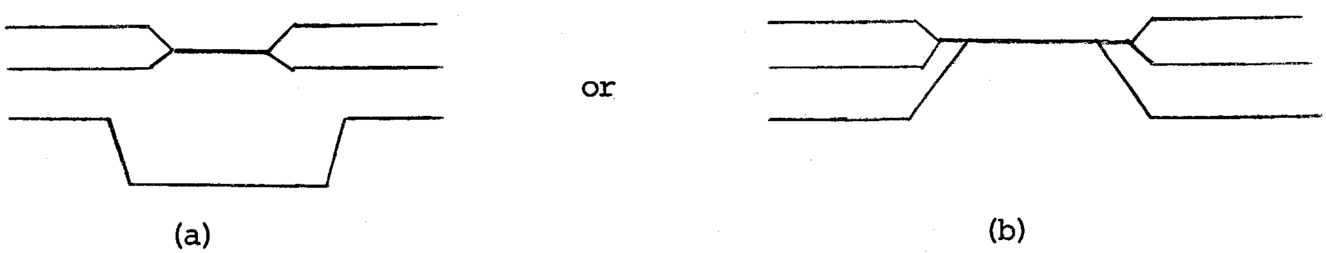
The intermediate case of three rings avoids the excess of intangibles associated with a limitation to two rings and the full brunt of the cost implications of the "everything separate" proposition, yet offers sufficient challenge to the designer's ingenuity. A typical cross section through either of the semicircular arcs at the ends of the racetrack would show two superconducting magnets for transport of protons and a conventional magnet electron ring stacked in a vertical plane. Each arc presents three spigots to the long straight sections of the racetrack and a suitable number of interaction regions are to be arranged in the intervening space.

The design problems of the arcs are relatively well defined, up to the uncertainties of superconducting magnets. The straight sections are more complicated, even if we set aside for the moment the questions of intersection optics.

If there were no experimental equipment in the vertical plane defined by the rings, then intersections could be made as sketched below



with the rings spaced vertically by small distances as in the semicircles. But at least in some interaction regions, equipment will surround the intersection point, so something must be done with the "other" pipe in this vicinity. Even if one were to give up at the outset the idea of eventually running all three rings simultaneously, only a partial simplification results. There appear to be only two alternatives (other than insisting that a hole be left in experimental equipment):



In (a) on the preceding page, the distance from the intersection point to the other ring could be 5 meters or so. If the offset were done vertically, the interference with activities at the interaction region would be less than if the offset were horizontal. The situation depicted in (b) raises questions of optics and beam dynamics - does it make any sense to even talk of three beam operation, when at certain interaction points the third beam would have to pass close to a nearby intersecting pair?

It should be noted that in the racetrack geometry, where straight section lengths are comparable with the mean radius of the bends, bypasses become geometrically reasonable, though expensive.

IV. A Few Topics to Consider

At this stage, it is not difficult to think of items needing study, and the list below is not intended to be all-inclusive. A few more specific questions follow some of the items.

- Civil Engineering	Is general layout indeed suitable insofar as bedrock elevation is concerned? Which direction is the better for bypassing the "third" ring from this viewpoint? Drainage questions.
- Shielding and Radiation Safety	What are the ground rules? What are consequences of inadvertent loss of 10 amp, 1000 GeV proton beam? Are "hot" access bypasses possible?
- Experimental Facilities	What are the arguments on the mix of types of crossings (e-p, p-p, high-low-intermediate beta)? Horizontal versus vertical crossing. Minimum requirements for experimental areas. Interference between experiments.
- Superconducting Magnets	Field quality and aperture requirements, and the prospects of achieving them with superconducting magnets. Reliability. What is low energy limit likely to be on this scale? Comparison with 400 GeV alternative - conventional use of steel with superconducting coils.
- Vacuum Systems	What are the requirements? What are relative advantages of cold and warm bore? What are implications for aperture and packing factor?
- Beam Dump-Abort	How does one dispose of the proton beam under scheduled and unscheduled circumstances?

- Proton Source	What does use as storage ring injector imply for Energy Doubler design? If Doubler is not built, what changes in proton ring design would be necessary to permit acceleration? Filling times and effect on fixed target experimental program.
- Electron Source	Suitability of present booster and main ring as electron accelerator. Interference with fixed target program. Criteria for a separate electron accelerator.
- Proton Injection and Stacking	Straight section length required. Stacking rf system. Scraping.
- Electron Ring	Factors limiting lifetime. Aperture requirements and magnet design. Radiofrequency system (proton beam is unbunched so number of electron bunches not tied to luminosity).
- Crossing Optics	Need critique of existing low beta design for p-p. High and intermediate beta proposals for p-p do not yet exist, nor do e-p crossing schemes. What are criteria? Provision for crossing control. What degree of variability of crossing region parameters between filling and interaction is needed? What are stay clear requirements for experiment design?
- Crossing Dynamics	To what degree are the beam-beam limits understood? Does the long range beam-beam interaction permit the use of much common beam pipe in the neighborhood of the interaction region? What is the state of our knowledge about the stability of an unbunched proton beam intersecting a bunched electron beam? What about three beams in a single pipe, with two of them intersecting? Lifetimes.

- Single Beam Dynamics — What are the consequences of two-fold symmetry in quantitative terms? Single beam collective effects. Lifetimes.

- Luminosities — Are the luminosity goals stated at Aspen realistic? This question occurs last, since its answer depends on the degree of insight gained into the various items in the list above.

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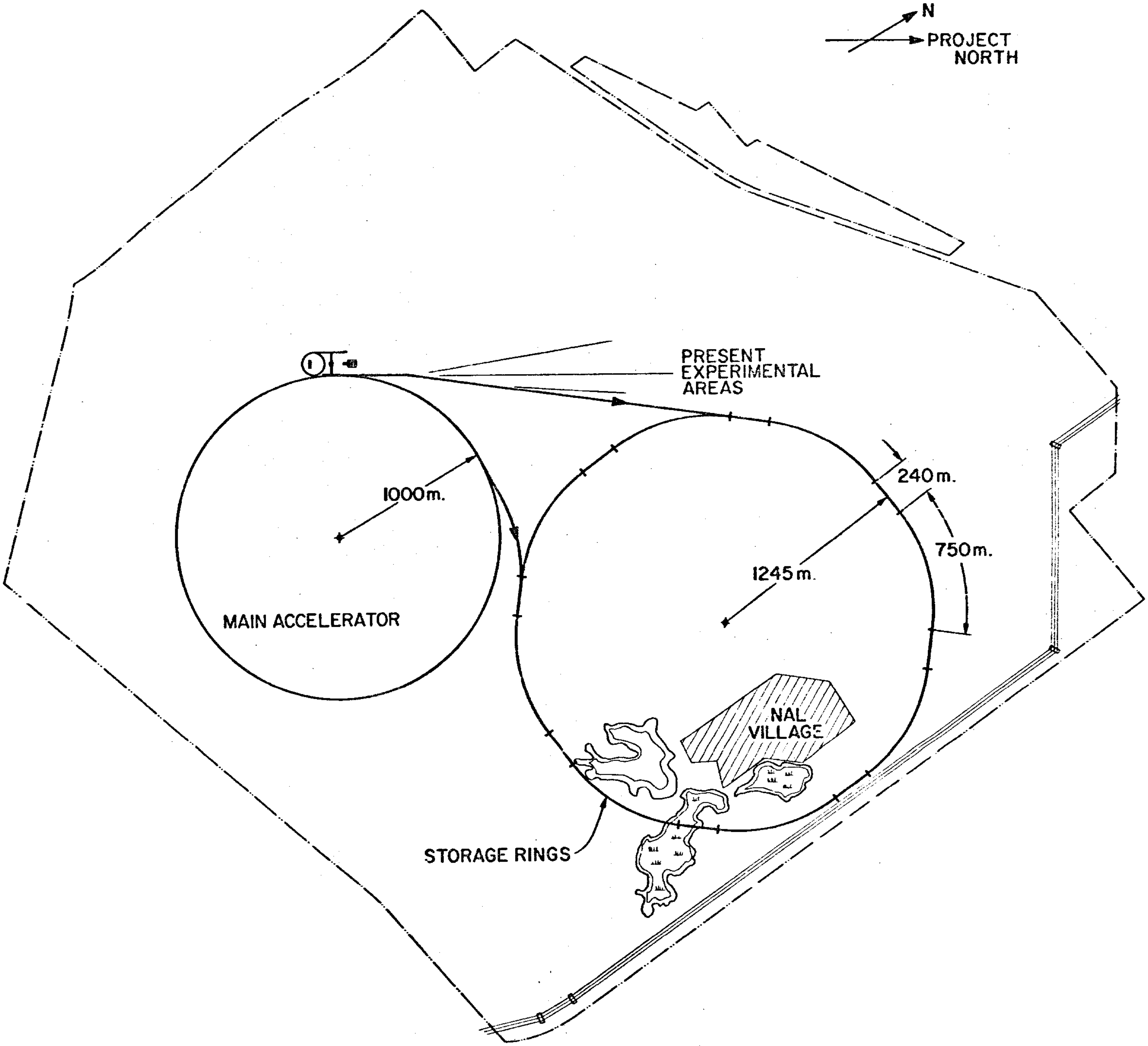
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PROJECT NORTH
PRESENT EXPERIMENTAL AREAS
1000m.
MAIN ACCELERATOR
240m.
750m.
1245m.
NAL VILLAGE
STORAGE RINGS